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Urbanising Delta: What Lessons Dhaka Offers to Face Challenges

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ABSTRACT

Cities built on deltaic regions are always prone to environmental risks like aggravated flooding, wetland reduction, compromised water quality, continuing water scarcity, and tainted air and these have been remarkable as the challenges while urbanizing deltas. On top of that, rapid urbanization adds more to the deterioration of ecosystem functions. Drawing insights from Bangladesh's capital Dhaka lying in the Ganges, Brahmaputra, and Meghna basin, this study basically appraises the common concerns of deltaic megapolises through a systematic literature review. The current literature has been brought up by analysing the status, factors, and impacts of the challenges and management by authorities. In addition, it is further updated with some urban experts' views, secondary records on groundwater levels, and remote sensing imageries. This paper also concludes with recommended guidelines from the reviews for more practical deltaic urbanization, especially when there is no turning back for urban transferability to a new region of the delta. Particularly, success demands (1) specifying current situation in quantifiable terms (e.g., numeric values, percentages, scores, indices), (2) practical but adaptive multi-objective plans/policies with a set of assessable targets, and (3) timely robust evaluation for tracking data for specific, measurable, and meaningful outcomes.

Keywords: Megalopolis delta; Growing competition; Ecological security; Continuing challenges; Practical solution; Dhaka

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1. INTRODUCTION

Urbanization of any delta is relatively more complex with social-ecological (dys)functions than any other conventional city (Meyer, 2016). The traditional inverted U-shape of the environmental Kuznets curve (EKC) is even claimed to become alarmingly downward sloping when urban development is added (Katircioglu et al., 2018). Specifically, Asian deltas are few of the most vulnerable among deltas in other regions of the world in terms of human suffering because of their dense population exposures (Seto, 2011). With the global urbanization trend (i.e., 68% rise of city-dwellers by 2050), it is becoming more and more difficult to ensure sustainable development without proper management, especially in low-income and lower-middle-income countries where urbanization is expected to be the most rapid (United Nations, 2018). This rapid growth puts unexpected pressure on the cities' abilities to provide basic services such as adequate housing, electricity, water supply, healthcare, education, and jobs (Buhaug & Urdal, 2013). On the other hand, any anthropogenic activity impeding the deposition of fresh sediment fluxes in the basins can result in an accelerated relative sea-level rise and increased risk of flooding (Van Koningsveld et al., 2008).

Like many other deltas globally, Ganges-Brahmaputra-Meghna (GBM) basin also faces challenges of climate change and frequent flooding (Barua & Van Ast, 2011). Application of river basin approach, practices of sustainability of ecosystem functions, maintaining green spaces, etc., are compromised when it comes to its metropolitan capital Dhaka. Here, rapidly expanding urbanization demands ultimately end into contaminated water, depleted water table, grabbing of lands by infrastructures, impaired air quality from traffic, and so on. Eventually, risk avoidance and adjustment choices force trade-offs between the benefits (resources) from the city and increasing costs (e.g., compromised human health, comfort) creating multifaceted issues. Deltaic cities of Nile, Red, Pearl, and Yangtze rivers and their issues with urban villages (i.e., informal settlements) are no exception in this regard. A solution to the mega problems of megacities requires a holistic (systematic) approach; but consensus-building among multiple stakeholders takes longer time. Thereby, delta management of cities needs to forecast the order of magnitude of future requirements and then to translate it back to current actions worked out ahead of time. Though several studies can be found about the Pearl River and Yangtze River delta urbanization (Gu et al., 2011), there have not been many detailed literature reviews about the deltaic cities' approach towards practical solutions after facing multiple challenges due to urbanization. Especially in case of the Ganges-Brahmaputra-Meghna (GBM) basin, delta reviews had not been well documented.

This review paper attempts to summarize the impact of the challenges that arise while urbanising a delta by exhibiting the existing overall situation of megalopolis Dhaka (a case for GBM delta) through the assessment of the current condition, steps taken, regulatory constraints in most practical methodologies, and externalities that have crippled the effective pathways toward facing the challenges. There remains a surprising dearth of studies examining the processes. As a result, from this paper, deltaic urban areas around the world with Dhaka-like circumstantial context are expected to facilitate themselves by figuring out and analysing the challenges that had already appeared or will appear for them. Lastly, this paper can be considered as a systematic literature review of recommended guidelines required that show the alternatives that a delta can adopt for urbanization when there is no turning back for the urban area transferability approach.

2. RESEARCH METHODS

2.1 Study Area

With its position at downstream of the GBM basin, Bangladesh has its capital Dhaka located in the centre. The Tongi Khal bounds city's 306.4 km^2 area in the North, the Buriganga River in the South and Southeast, the Turag River in the West, and the Balu River in the East (Figure 1a). Dhaka lies between 23^{o}40' to 23^{o}54' North latitude and 90^{o}20' to 90^{o}30' East longitude. Dhaka gets the experience of the wet tropical climate with an annual average rainfall of 2,500 mm. Most parts of it are situated in low-lying areas with a small proportion of highland, free from annual inundation, which is situated at the southern edge of a Pleistocene terrace with an elevation of 6.5 to 9 m above mean sea level.

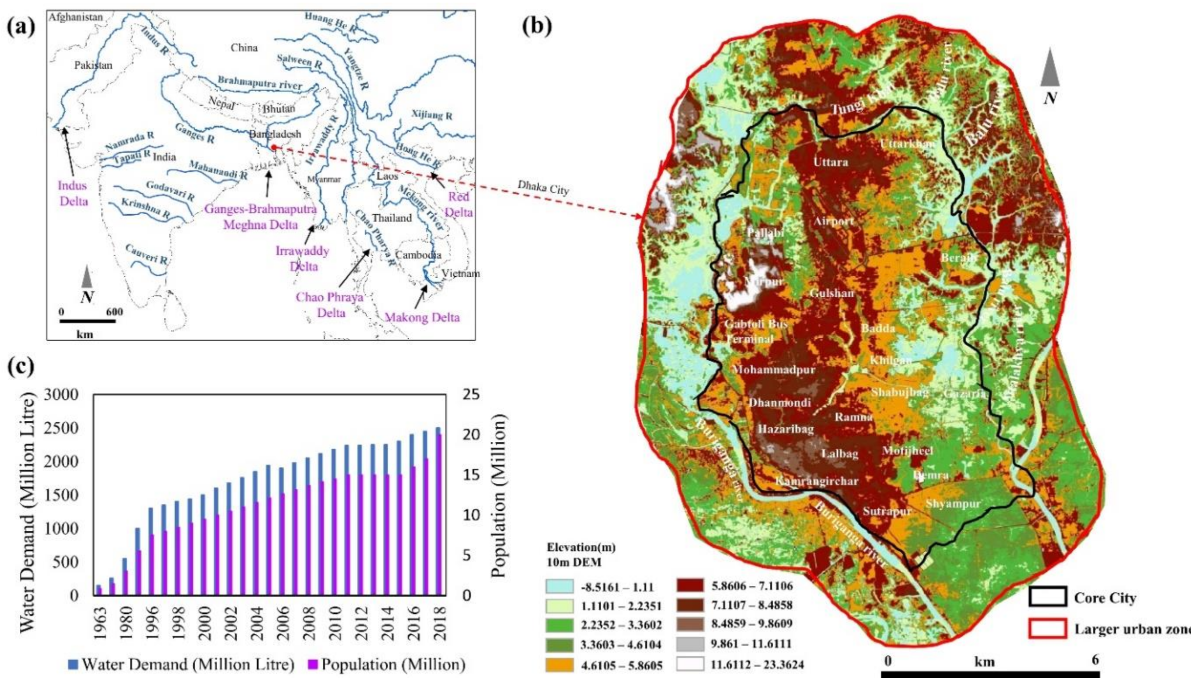

Figure 1(a): Location of the Ganges-Brahmaputra-Meghna (GBM) basin among the Asian mega deltas where major rivers are shown with blue lines and international political boundaries are indicated as black lines. Figure 1(b): Topography Map of Dhaka city, Bangladesh. Figure 1(c): Bar graphs showing demography and growth of water demand for the core city since 1963 (Source: Dhaka Water Supply and Sewerage Authority [DWASA]), 2014).

2.2 Methods

Most qualitative information about Dhaka, its plans, and policies are retrieved from literature reviews of published articles or reports accessed via online means and urban experts' views (supplementary Annex-1). The quantitative study about the groundwater table declination over the years 1980-2018 was conducted by collecting secondary data from the Bangladesh Water Development Board (BWDB), Bangladesh Agricultural Development Corporation (BADC), and the Department of Public Health Engineering (DPHE). The Digital Elevation Models (DEM) data from Shuttle Radar Topography Mission (SRTM) and images from Landsat-8 OLI satellite of January 2018 were processed to assess the current drainage density thematic layer and land use/cover map, respectively.

3. CHANGE IN LANDFORM

"Natural" infrastructures (i.e., wetlands) are an essential feature of "turquoise" (i.e., combining green and blue) infrastructure (Childers et al., 2015) in virtually all bottomland cities. But shifting from an ecology of urban to ecology for urban restricts the city's ecotone ecosystems. In essence, megacities limit natural functions of ecological services, fast growth offers optimal "commodity" in many city locations, and later, urbanised delta will end up with poor livability. Megalopolis Dhaka has been going through such processes.

3.1 Wetland Reduction for Urban Growth

Most of the eastern part of Dhaka used to contain open water bodies like the marshland of the Balu River floodplain and the western fringe had low marshy lands in 1968 (Sultana et al., 2009). In 1978, 130.17 km^2 of wetland existed (Habiba et al., 2011) that eventually started to reduce turning to sporadic patches (Sultana et al., 2009) at an alarming rate since 1989 (Islam, 2009). Only 9% of western water bodies of 1963 were lost by 1990, whereas it jumped to 28% by the year 2000 (Reza & Alam, 2002). In 2011, the number of wetland areas went down to 53.6 km^2 (Habiba et al., 2011) showing 502.5 hectares/year rate of wetland loss during the 1989-1999 period, and 1922 hectare/year loss during 1999-

2005 (Islam, 2009). Such shrinking is attributed to unplanned progressive urbanization, landfilling, encroachment, and lack of coordination between government agencies (Habiba et al., 2011). It is also evident that if this losing trend of the ecotone ecosystem is continued, by 2035 (Figure 2), Dhaka will lose all of its temporary wetlands (Islam, 2009). This may impact adversely resulting into (i) further waterlogging and flooding, (ii) decrease in groundwater recharge areas, hence, decline of groundwater level, (iii) destruction of natural drainage system, (iv) disturbance in local ecology and biodiversity, (v) destruction of aesthetically pleasant recreational sites, and (vi) increase in Impervious Surface (Habiba et al., 2011).

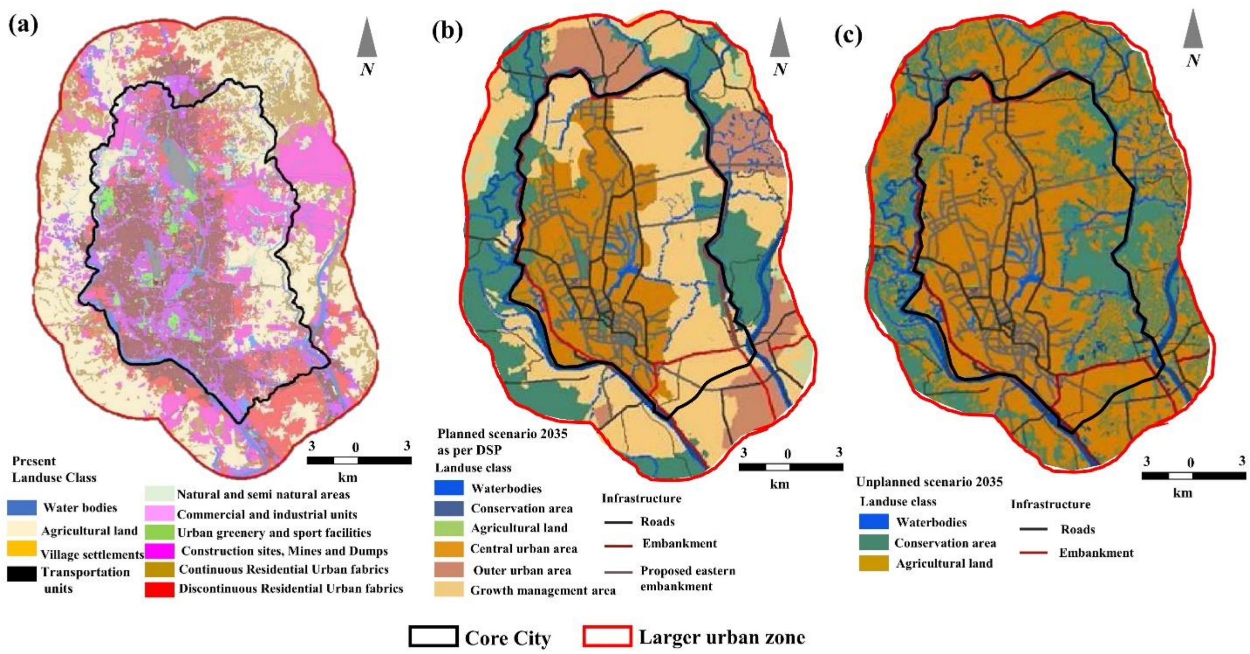

Figure 2(a): Dhaka's land cover and land use pattern in 2017 as per the prediction of Ahmed et al. (2018). Figure 2(b): Probable planned urban growth by 2035. Figure 2(c) Probable unplanned urban growth by 2035 based on Revised Dhaka Structure Plan (2015-2035).

Previously, Dhaka Metropolitan Development Plan (DMDP) for 1995-2015 had designated flood flow zones where the change to natural topography was restricted (Islam, 2009). Despite enacting various environmental laws and policies, private land developers have been encroaching, notably diverging from the city structure plan policies (Islam, 2009). The government of Bangladesh has expressed concerns about the loss of wetlands due to rapid urbanization in the Bangladesh Delta Plan (BDP) (Bangladesh Planning Commission, 2018) and announced strategic plans that will preserve urban wetlands and promote green and blue spaces. Moreover, the Detailed Area Plan (DAP) imposes strict land development regulations according to the hydrology of the area (RAJUK, 2018). For instance, DAP prohibits sand filling by using dredgers, forbids obstructing the flow of water current in some specified areas, and discourages infrastructures and constructions on wetlands, while expressing the need to construct water retention basins to conserve water. These are appreciable promises regarding preserving and restoring the wetlands for Dhaka city.

3.2 Rapidly Expanding Informal Settlements

One of the unavoidable challenges that a developing city faces is overcrowded urban cores with a lack of spatial coordination between housing and jobs (Cervero, 2013). Dhaka, being the 11th largest city globally in terms of population (Bird et al., 2018), is not free from such remarkable challenges either. The population of Dhaka is increasing rapidly, with an increment of 2 million from 1991 to 2001 and 9 million from 2001 to 2011 (Figure 1b) indicating the migrants' predilection for Dhaka as the primary choice to live in (Ishtiaque & Mallik, 2011; Population Reference Bureau, 2010). As a consequence, out of 85.3% of total urban migrants, 68.3% are pulled by Dhaka city alone (Biswas et al., 2019). Urban pull factors for

such internal migration can be attributed to the concentration of resources, employment opportunities, educational facilities, and access to the informal economy. Besides, climate change impacts in the GBM basin will continue to increase rural push factors, e.g., natural disasters leading to eviction threat, scarcity of freshwater, lack of food, poverty, etc. (Bangladesh Planning Commission, 2018; Ishtiaque & Ullah, 2013). As worst-case scenarios of future under climate change threat, the poor will be forced to become environmental refugees as the 'last resort' migrating (Penning-Rowsell et al., 2013) from coastal rural areas towards megacity, Dhaka.

Mostly, the urban migrants settle in informal settlements and new climate refugees will speed up amorphous informal developments (Saha, 2012). According to Angeles et al. (2009), Dhaka's overall gross population density is about 29,857 persons per square km, whereas informal settlements display 220,246. As informal settlements are non-legalised, the dwellers are deprived of basic rights, rising to issues like tenure insecurity, fire tragedy, insufficient drainage, internal flooding, unwanted garbage disposal, poor access to utility services including freshwater and safe latrines, etc. (Mohit, 2012). The presence of many migrants deteriorates the urban environment resulting in a very low standard of living for them (Jahan, 2012). In fact, according to Economist Intelligence Unit (EIU) liveability index 2015 (Bird et al., 2018), Dhaka's position is 139th among 140 cities based on health, education, stability, and infrastructure. The migrants get engaged in informal jobs that have no accountability in Gross Domestic Product (GDP) and Gross National Product (GNP), no imposition of the tax, and are not under government monitoring (Barmon, 2011).

At the expense of a cheap labour force for the city's productivity, Dhaka has been systematically creating a stressed ecological area by polluting and destroying a range of ecosystem services (Dewan et al., 2012) with the rampant expansion of informal settlement pockets and extraordinary density of informal settlements-dwellers. Nowadays, informal settlements across the world are considered unprecedented incubators of many diseases, such as breeding grounds for vector-borne dengue (Ferdousi et al., 2015; Marti et al., 2020) and malaria (Rashid et al., 2013; Sclar et al., 2005) that are increasing due to drainage congestion, stagnant water, flooding and improper disposal of solid waste. Citizens must remind themselves that emerging and re-emerging diseases can travel across the city if informal settlements are neglected or ignored. Recent outbreaks of severe dengue in 2018 (Mutsuddy et al., 2019) and the spread of regular malaria (Rashid et al., 2013) in the city triggering casualties is a case in point. On top of the current agony of informal settlement dwellers, the contemporaneous COVID-19 pandemic has pushed the informal settlements into more tragic life forms (BRAC [Producer], 2020). Informal settlements are the potential sources of the virus spreading as social distancing is a utopian term for these densely populated areas. Moreover, it is apparent that the lockdown just has added another nail in their coffin as a day without work means no food at all. From the inspection of these tragic situations, scientists concluded that the lifestyle of the informal settlement- dwellers has now come to rest with trouble at both ends, either go out for food and get infected or stay at home and starve.

So far, several projects and policies have been approached by government organisations (GOs) and NGOs. Out of which, most notable informal settlement-related approaches include chronological encroachment-grounded eviction (Wakely, 2007), major resettlement (Mohit, 2012), upgrading, back to home ('Ghorephera') program, rehabilitation, contracting for health services (Ishrat & Siddika, 2019; Tripathi, 2008). 'National Rural Development Policy 2001' also indicated high awareness of rural-urban migration risk, however, limited evidence of the practice is witnessed equitable growth or the decentralization of power, finance, and infrastructural development towards the rural area (Afsar, 2003).

4. WATER SECURITY

According to the National Water Security Index score by Asian Development Bank (ADB), the Bangladesh of GBM basin has been struggling with water security as it is ranked 44th among 48 nations (Asian Development Bank, 2016). In this paper, indicators like the accessibility of adequate safe water in human and environmental services, protection from hydrological hazards like flood and drought, sustainably using water systems and resources, and protecting them collectively comprise the term water security. Mostly mentioned water security problems are waterlogging or poor drainage systems, insufficient sanitation system provision, scarcity of water, flooding, and pollution through urban and industrial wastes and chemicals (Schultz, 2007) are described in detail as follows:

4.1 Flood

Dhaka city's flood is a common occurrence with a history of most devastating forms during 1954, 1987, 1988, 1998, 2004, and 2007 (Figure 3). Flood volume is largely affected by further increase in peak runoff along with growth in impervious surfaces of built-up areas (Subrina & Chowdhury, 2018). Several structural measures have been taken as a response to the damages made by those floods. For instance, promoting efficiency in outpouring extra water by the pump and raising numbers of pumping stations became priorities (Bala et al., 2009). In this regard, emergency management by the civic bodies, namely, DWASA, Bangladesh Water Development Board (BWDB) and Dhaka South City Corporation (DSCC), was highly appreciated in the past flood events. Nevertheless, dewatering a large volume of floodwater can be only an immediate temporary solution.

Furthermore, external flooding is not the only difficulty during the monsoon season. Three past flood events of Dhaka confirmed that waterlogging due to local rainfall is also responsible for internal flooding, particularly the case of the 2007 flood (Bala et al., 2009). In general, intense rainfall causes waterlogging in Dhaka West due to the Dhaka-Narayanaganj-Demra (DND) embankment encircled area performing poorly in drainage maintenance, whereas river flooding damages Dhaka East that has no embankment (see Figure 4) (World Bank, 2015). Note that the natural drainage of Dhaka city is connected with rivers surrounding the city by retention areas such as Dhanmondi lake with a retention capacity of 4.4×10^5 m^3 and also by 40 drainage channels (Tawhid, 2004). It is believed that the resuscitation of the blue networks is a foremost requisite for solving city waterlogging (Subrina & Chowdhury, 2018).

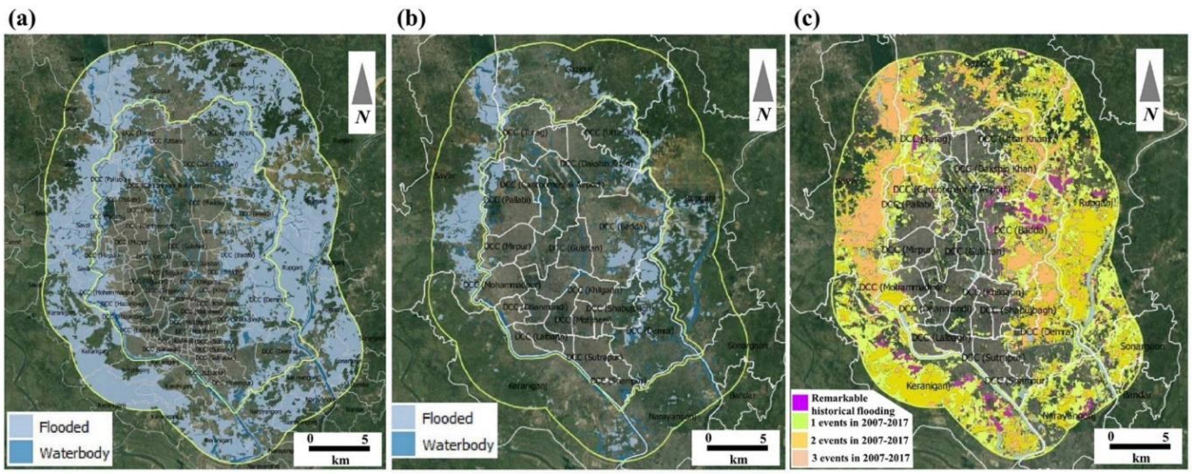

Figure 3: Flooded areas within Dhaka for the flooding event on (a) 10 August 2017 and (b) 24 August 2017; (c) Flood hazards within Dhaka based on flooding events from 2007-2017 (Haeusler et al., 2017).

Regrettably, lack of coordination among the concerned authorities is also blamed by communities for not taking timely flood action (Faisal et al., 1999) and was witnessed during 1998 floodwater intrusion, especially through embankment breach along the 2.2 km long section of the Buriganga River and through open regulators into the raised section of the Dhaka west from Balu River (Bala et al., 2009). However, an opposite scenario was observed during the 2004 flood. In this event, a well-coordination among the DWASA, BWDB, and DSCC in case of the on-schedule closing of the regulators and sluice gates of the flood protective embankment firmly made western Dhaka free from the floodwater. DWASA has the major responsibility to manage stormwater dividing the city into 12 drainage zones for the stormwater drainage with a total area of 140 km^2 (Tawhid, 2004). In parallel, DSCC contributes to sludge management by constructing the 130 km underground piped drainage along with 1,200 km surface drains (Tawhid, 2004). Despite such extensive drainage network planning, waterlogging in Dhaka is prominent due to blockage originating from various anthropogenic factors (RAiN Forum [Producer], 2020). These include (i) faulty waste management system, (ii) local dumping of solids/garbages encroaching the drain, (iii) illegal encroachment of major rivers, (iv) reduction of water retention areas, and (v) unplanned haphazard development of the houses/city for fast-growing population resulting in the disappearance of natural waterways. In most of the cases, civic bodies end up in blame game instead of solving problematic cases through mutual integrity and cooperation. Every monsoon, DWASA and DSCC constantly get away by

blaming each other when chocked drains lead to waterlogging. When it comes to drainage within flood-control projects, dilapidated river banks and indiscriminate filling of low-lying floodplains, a bunch of barriers like authoritative prolongation, no magistracy power, fund shortage etc. are quite common for BWDB, Bangladesh Inland Water Transport Authority (BIWTA) and Rajdhani Unnayan Kartripakkha (RAJUK), respectively, ultimately posing threats to ecological functions affecting the city.

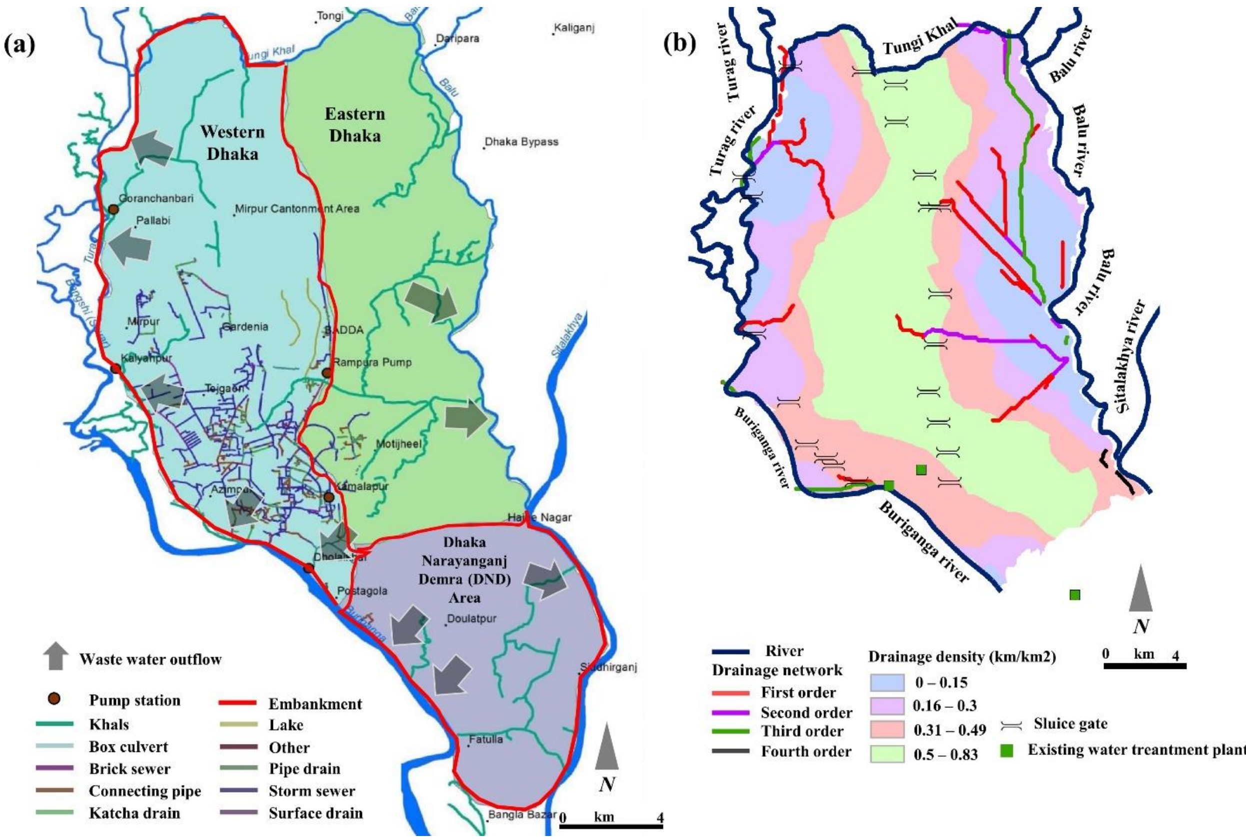

Figure 4: (a) Existing significant flood control and drainage infrastructures along with outfall points of wastewater shown by black arrow markers (DWASA, 2016); (b) Drainage density and drainage network for Eastern and Western Dhaka.

During any flood in cities with poor sanitation, the high mortality rate due to the spread of waterborne infectious diseases is prevalent (Mark et al., 2018). Among the waterborne diseases, cholera transmission through flood water contact is one of the natives to Dhaka and the estimated average cholera risk per day for children is 10 to 70 times more than adults in the city (Mark et al., 2018). If the monthly maximum temperature increment is 1°C, either due to urban heat island effect or climate change impact, cholera incident is predicted to show an increment of 7% ($p < 0.001$) (Daisy et al., 2020). Again, when the floodwater level retreats in Dhaka, a suitable breeding environment for *Aedes* mosquitoes is created (Hashizume et al., 2012) leading to the dengue outbreak to a large extent. Currently, early warning and early predictions are used to restrict its destructive effect.

As part of tackling future floods, the newly designed storm sewerage system has now considered 100-year return periods to enhance water delivery capacity. Note that the previous design was based on 25-year return periods. As a result, water drainage takes a couple of hours that previously used to take 2-3 days. However, maintenance and poor or no monitoring issues still remain unresolved. Despite all the odds, the Wetland Conservation Act 2000 targets saving Dhaka from frequent flooding through increasing wetland areas, including 40% of Dhaka (Subrina & Chowdhury, 2018). One of such successful steps is the Hatirjheel – Begunbari re-excavation project, as it made the capacity of stormwater detention increase from 14,25,837 m^3 to 22,01,601 m^3 (Subrina & Chowdhury, 2018). It was jointly carried out by RAJUK, DWASA, the Local Government Engineering Department (LGED), and the Special Works' Organization (SWO) of the Bangladesh Army. This is definitely an excellent example of administrative

authorities of Dhaka city coming forward to cooperate with each other resulted in significant progress towards targeted bottom catchment urbanization.

4.2 Surface Water Contamination

Serious river pollution problems are common to any Asian megacity (Luo et al., 2019; Niemczynowicz & Iwra, 1996) due to industrial effluences and, partly, wastewater contamination exacerbated by population growth. Dhaka megalopolis is no exception, as rapidly growing urban development and residents continue discharging heavily polluted wastes to the environment. Without adequate wastewater treatment, water pollution continues to be a major challenge. About 3,300 tons of municipal solid wastes are produced in Dhaka South and Dhaka North per day (World Bank, 2015), stemming mostly from residential and commercial sources like industries (Bahauddin & Uddin, 2012). On top of that, 206 tonnes of contagious medical waste generation per day created a dire situation (The Business Standard, 2020). Approximately 50,000 septic tanks and pit latrines exist in Dhaka in addition to the (piped borne and waterborne) sewerage systems that cover 60% of the total area, and the rest of city dwellers do not have any type of sanitary disposal system actually (DWASA, 2019). As the DSCC fails to cover the rapidly growing Dhaka outskirts, about 1,100 tons of waste remain uncollected (World Bank, 2015). Despite the solid waste master plan and National 3R Strategy of the Department of Environment (DoE) (World Bank, 2015), the uncollected wastes are dumped in lowlands and other public areas (Bahauddin & Uddin, 2012). As a result, rivers get polluted directly or by the leachate from the wastes when rainwater gets swept through the dumping sites (Islam et al., 2015). Best practice dictates that improving water quality requires wastewater collection, blockage-free connection to sewerage, and ultimately wastewater treatment.

On the other hand, while running the economy through ensuring high-wage employment for a mass along with increasing productivity of valuable goods on a large scale (Yunus & Yamagata, 2012), thousands of industries are discharging their effluents in the rivers around Dhaka degrading the water quality (Islam et al., 2016). The chemical oxygen demand (COD) of tannery wastewater samples varied between 90 to 6,500 mg/L and was much higher than non-tannery wastewaters (Islam et al., 2015). For a further clear scenario, variation in physicochemical and toxic metal concentrations of Shitalakhya, Buriganga, and Turag River around Dhaka city due to tanneries, textiles, dyeing, pulp and paper, and steel re-rolling mill is given in table 1. To neutralize severe contamination effects, 148 industries were asked to relocate from the Hazaribagh area to Savar by 2017. Transferring all the said industries was a major initiative, and this relocation process solved the Hazaribagh area's local pollution issues to some extent. Now, biochemical oxygen demand (BOD), electrical conductivity (EC), ammonia (NH_3), and nitrite ion (NO_2^-) concentrations in the Buriganga River show a decline. For instance, chemical oxygen demand (COD) values before and after relocation were found to be in the range of 65-140 mg/L and 55-85 mg/L, respectively (Islam, 2018).

However, shifting the industries upstream of the rivers, though it has shown an immediate local reduction of contamination, is not a sustainable solution (Rampley et al., 2020). Industrial metals are still gradually transported downstream and will continue to contribute in the long run (River Conservation Club [Producer], 2020). High toxicity due to critical heavy metals like chromium, zinc, and selenium with conductivity value touching the danger level of 944-1,001 μs/cm is present in river water around Dhaka. Moreover, the soil in the Hazaribagh area still contains contaminants such as lead and chromium in concentrations between 0.05 to 3.66 mg/kg and 7.20 to 21.15 mg/kg, respectively (Rampley et al., 2020). Thereby, scientists still find these relocated industries as significantly threatening sources and a future threat with the probability of endangering the groundwater quality when the groundwater level is recovered (Khan et al., 2020).

4.3 Groundwater Table Depletion and Water Scarcity

Due to intensive withdrawals in megacities, the dramatic lowering in groundwater levels persisted for ages (Islam et al., 2021; Kagabu, et al., 2011; Onodera, 2011). Dhaka is one such city characterised by a significant cone of depression with water table elevations of -49 to -69 m during 1980-2018, where groundwater abstraction now exceeds recharge. Against the demand of 2,500 megaliters per day (MLD) at 160 liters per capita during 2018-19 (Figure 1b), DWASA has actual production ranging from 2,250 to 2,450 MLD (DWASA, 2019). It is also noted that 84% of the total municipal water supply system is based upon groundwater (Hoque et al., 2007) and the rest is from three surface water treatment plants, of which

the largest one has a capacity of 225 MLD (DWASA, 2019). More than 700-800 pumping wells (henceforth referred to as tubewells) of DWASA operate at a rate of 20 to 22 hours daily for lifting groundwater (BADC, 2019).

Table 1: Water quality parameters of Shitalakhya, Buriganga, and Turag River (adapted from Islam and Azam, 2015; and Islam et al., 2015b).

Parameters	*Experimental Range*			*Standard Permissible Limits*	*Remarks*
	Shitalakshya	*Buriganga*	*Turag*		
Potential of Hydrogen (pH)	6.5-8.3	5.9-9.1	4.1-9.8	6.5-9.0	pH values are within the permissible limit except for Buriganga River
Electrical Conductivity (EC), µS/cm	720 -2321	354.5-2850	555.3-1990	700	The measured EC of Shitalakshya River was below than acceptable range
Total Dissolved Solids (TDS), mg/L	475 -1180	169 -1260	41-1510	1000	The TDS values of all measured samples fell within the permissible limit of drinking, industrial, and agricultural use.
Biochemical Oxygen Demand (BOD), mg/L	25.1 -146	38.9-151	42.3-179	0.20	The BOD values obtained in the present study indicated that all the river water is unsuitable for use.
Chemical Oxygen Demand (COD), mg/L	14-172	17-185	5-181.7	6	Buriganga River showed the highest COD value.

By analysing records from the monitored borehole network, severe water mining was observed for 1998-2018 (Figure 5a-b) as the number of deep tubewells has been increasing every year since 1980 (BADC, 2019). Nevertheless, seasonal rainfall could not reflect any impact of recharging the Dupi Tila aquifer beneath Dhaka due to the impermeability of Pilo-Pleistocene (i.e., Madhupur tract) soil (BADC, 2019). On top of that, most soakable green areas have already been transformed into an impermeable concrete jungle. Here roads are creating further restrictions on rainwater penetration into the ground (Subrina & Chowdhury, 2018). This is why major runoffs drain out to nearby surface water and sewer systems without recharging the underneath. During 1980-90, the groundwater level lowering rate was below 1 m per year. Since 1996, this yearly lowering rate increased to 2 m showing a sharp decline since 2004 when 5.5 m dropped down in one single year (Figure 5c). This indicates that Dhaka city's groundwater situation reached a precarious condition. On average, the declination rate across the study area was 2.4 m/year for the monitored period (1994-2013) (Nowreen, 2017).

In order to safeguard the falling groundwater level, artificial recharges (Figure 5d) have been encouraged by the government, particularly by promoting rainwater harvesting and partly by injecting wastewater underneath after treatment. However, to date, experts are a bit skeptical about the consequences of wastewater injection (RAiN Forum [Producer], 2020). Then, again, as part of the pandemic prevention schemes, additional cleanliness requirements for COVID-19 may add pressure to water scarcity. According to the World Health Organization (WHO) guidelines, frequent and proper handwashing with soap points to a major increase in clean water demand in the cities.

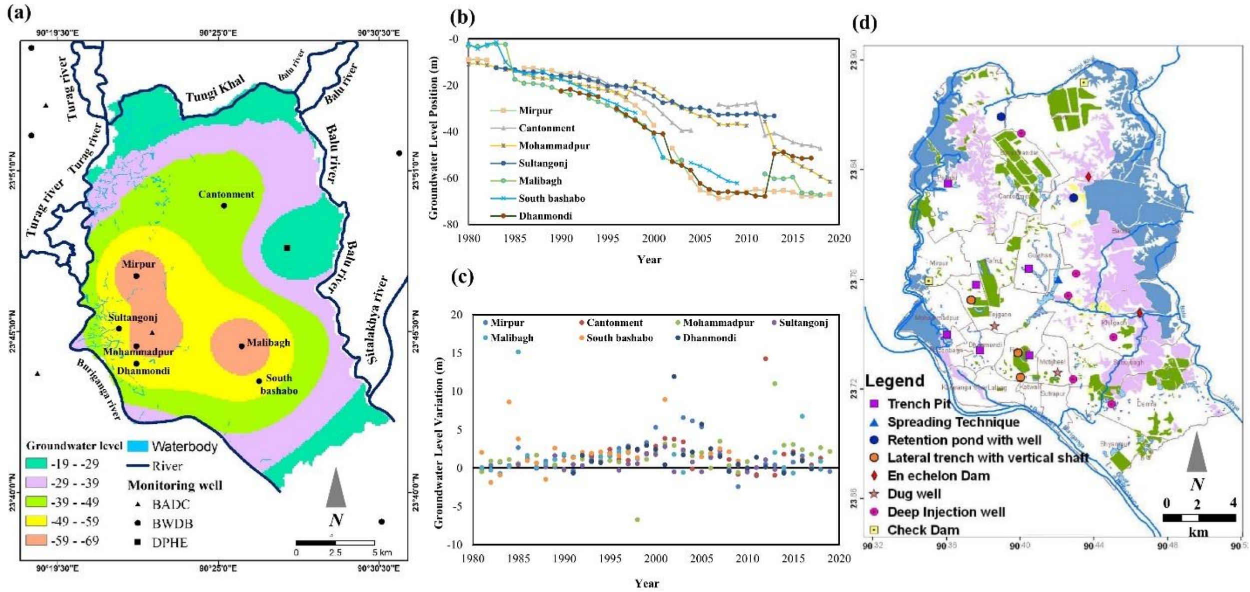

Figure 5: Groundwater level condition of Dhaka City. Here, (a) map shows the spatial distribution of groundwater level position (m below ground level) for the year 2018, where points denote monitoring wells of piezometers observed by Bangladesh Water Development Board (BWDB), Bangladesh Agricultural Development Corporation (BADC), and Department of Public Health Engineering (DPHE); (b) line plots show an annual groundwater level position during the period 1980-2018; (c) point graphs show year-wise anomalies (i.e., rate of declines) plotted against average (1980 – 2018) groundwater levels for the same observation points shown in (b), and (d) prospects of artificial recharge and other augmentation options proposed by Sultana (Sultana et al., 2009).

5. AIR QUALITY

Dhaka is ranked 2nd in the world in terms of the most annual average concentration of particulate matter (PM) - $PM_{2.5}$ - according to the 2019 World Air Quality report (IQAir, 2020). Increased activities and vehicular emissions in parallel to the growth of the economy are the primary contributing sources (Rahman et al., 2021). Every day there prevails about 100 kg of lead, 3.5 tons of suspended particulate matter (SPM), 1.5 tons of sulphur dioxide (SO_2), 14 tons of hydrocarbon (HC), and 60 tons of carbon monoxide (CO) from automobile emissions (Alam, 2010). In semi-residential areas, the minimum average PM_{10} mass concentration recorded during 1996-2005 was 10.5 $\mu g/m^3$ that changed to 27 $\mu g/m^3$ during 2006 - 2015 (Begum & Hopke, 2018). Substantial impact on public health (see Table 2) is likely to occur from high fine PM concentrations as measured by Gujrar et al. (2010). Note that the global position of Dhaka is the worst in three of the cases (Total, Respiratory, and Cardiovascular Mortality) and second worst in the last one case of table 2.

Table 2: Health risk in Dhaka in the late 1990s/2000 due to air pollution

Cases	*Number per year*
Total Mortality	14,700
Respiratory Mortality	2,100
Cardiovascular Mortality	7,000
Hospital Admission: Chronic obstruction pulmonary disease (COPD)	2,100

Note: The total and respiratory mortality rates are recorded in terms of total suspended particles (TSP), sulphur dioxide (SO_2), and nitrogen dioxide (NO_2) effects, whereas cardiovascular mortality is in terms of NO_2 only (Gurjar et al., 2010).

Taking air pollution into account among many government steps taken, remarkable are (i) conversion of 80% vehicles in 2010 to compressed natural gas (CNG) (Begum et al., 2011), (ii) the embargo

on the import of high sulphur diesel and coal (Alam, 2010), which reduced sulphur to 500 ppm by 2016 (Begum & Hopke, 2018), (iii) ban on importing lead petrol (Alam, 2010), (iv) restriction of registration of two-stroke three-wheelers by Bangladesh Road Transport Authority (BRTA) (Alam, 2010), (v) taking Urban Transport Project in hand (Alam, 2010), and (vi) target to remove 25 years old trucks, buses, minibuses from 15 July 2010 (Ahmed & Mahmood, 2011).

6. OTHER INESCAPABLE CHALLENGES

There may be some other challenges that create adverse impacts on the city. Among those, the challenges that have a relatively higher impact on the fastest-growing Dhaka (Hossain, 2013) include traffic congestion, electricity deficit (Mahin et al., 2017), the temperature increase for urban heat island effect (Tashnim & Anwar, 2016), seismic risk (Khan, 2016), etc. affecting society, economy, and the individuals. Notably, Dhaka now ranks the 10th most traffic-congested city in 2020 (Adamovic, 2020) and, according to Gallagher's (2016) prediction, the average daily traffic speed would go down to 4.5 kph by 2035, if 'no regret' phase continues.

7. RECOMMENDATIONS

The problem for one delta may not be the problem for the other, and a solution for one megacity may not be the solution for the others. Therefore, drawing insights from the impactful Dhaka issues discussed above, some generic and simplistic recommendations followed by Dhaka-specific opinions are suggested and categorised into policy, intervention, and research. However, ultimate outputs will never be fruitful if there is no strong intermediate ‘Evaluation’ or ‘Monitoring’ and no capacity/flexibility for adaptive planning or alternative pathways to achieve the same goal are undertaken on time. For these time-to-time evaluations, numerical data of baseline situation, quantifiable indicators and targets are timely and practical demands to track policy progress.

7.1 Policy

1. Coordinated decentralization by generating alternative urban centers can reduce urban growth (Childers et al., 2015). At least administrative decentralization is recommended along with shifting universities and garment industries either to peri-urban areas or intervening secondary cities. Empowering secondary cities will be helpful in this regard.

2. Integrated land-use planning has been recommended as a helpful technique (Roy, 2009). For instance, synergising roadway infrastructure mapping with water-connected river master plan applications should be elevated (Cervero, 2013). In Dhaka's case, the collaboration between RAJUK and Dhaka Transport Co-ordination Authority (DTCA) is recommended. Further, urbanization should not take the places of high-value agricultural lands and, of course, not take place in the flood-prone area. In this context, the plans like DMDP, Dhaka Integrated Transport Network (DITN), and Flood Action Plan (i.e., FAP no. 8A) are the tools for potential alternative analyses. The DMDP support system can be a suitable mechanism too (Roy, 2009).

3. Regulating the ecological function zoning by formulating laws with exemplary penalties and imprisonment is required. Effective enforcement of laws should be immediately carried out. Specifically, the wetlands of Dhaka should be classified as jurisdictional wetlands to preserve the existing retention storages (Islam et al., 2012).

4. Distributions of roles among authorities should be cast as per the suitability and proficiency of the administrative organization and their departments to make policies into practices (M. A. U. Rahman, 2015). In this regard, one single authority, preferably selected by the public, can ensure political support from down to top-level development. Khan (DWASA, 2012) stated that city corporations should take responsibility for both surface water and stormwater drainage systems for better performance. Rana (2011) recommends that municipal authorities or local governments handle urban planning like budgets with independence, whereas the central government should majorly focus on the overall master plan and development guidelines providence such that the fund, service, and resource facilities are ensured.

5. For executing plans, the integration or partnership approach should be given emphasis. In this context, DWASA, DSCC, and RAJUK can synergize national-level plans with sector budget allocations through short- and long-term action programme reviews (M. A. U. Rahman, 2015). It is recommended

that the Bangladesh National Adaptation Programme of Action (NAPA) like national strategies should line up with the actions of the DMDP (Roy, 2009). Also, merging similar functions like urban planning functions of DSCC with the DMDP are highly suggested (M. A. U. Rahman, 2015). Digitization for constant monitoring can further help to ensure coordination and end up the blame game probabilities, to be specific, between DWASA and city corporations. Coordination between city corporations in executing the strategies and master plans is now required more than ever.

6. Blending Top-Down and Bottom-Up Approaches can be initiated for a successful change. The public-private relationship should be strengthened. NGO activities that get troubled by bureaucratic regulations costing a lot of time should be changed. Immediately bottom-up development policies are to be implemented with reforms in administrative institutions (Rana, 2011).

7. Enabling the environment is a prerequisite with sound policy guidance. To avoid the corruption probabilities of RAJUK, a separate high-ranked regulatory authority for controlling development could be a better choice (Alam & Ahmad, 2011). Further, consensus-based implementation approaches should be initiated to stop the trend of the squatter settlement process (Swapan et al., 2017).

8. Integrated, inclusive and interconnected policies and planning are necessary, and implementation by the same organization is recommended. Further, formulation of policies on waste management related to infectious and contagious diseases (e.g., COVID-19) creates awareness on potential consequences of hazardous waste management, enactment of anti-waste dumping laws (The Business Standard, 2020), micro-level monitoring for daily cleaning routines with the unloading of solid dumps, and recycling strategies are recommended for minimising primary and secondary waste collection (World Bank, 2015). Specific to Dhaka city, amendment of the "Medical Waste (Management and Processing) Rules 2008" and its proper implementation is one of the demands.

9. Other recommendations include technical knowledge to incorporate in planning involving planners, architects, and engineers, no political influence on feasibility study reports, open-source information for better response/management.

7.2 Intervention

1. Envisioning multipurpose structures or blue cities can protect retention and detention areas and develop urban fringe areas to increase green networking (Lal, 2020) with more open spaces, water plazas, rainfall gardens, and rooftop gardening (Subrina & Chowdhury, 2018). The 'Sponge City' concept paves a better solution pathway in this regard. A sponge city is a modern stormwater management approach that allows a city to collect rainwater and use the stored rainwater when needed. Much like a sponge, the city will soak rainwater and stormwater instead of creating excess runoff. The target of a sponge city is to collect the floodwater at the rainfall location instead of building canals and drainages to try to get rid of the excess runoff (Nguyen et al., 2019). Using dams, gates, and pumps to try to escape from floodwater is becoming an outdated concept. Thus, it should be recommended to WASA that Dhaka too should start implementing the sponge city approach since the whole world is slowly moving in that direction. The first and foremost step for constructing a sponge city is to incorporate vertical gardening with large buildings. Some structures in Dhaka are already starting to use vertical gardening, as it can intercept the rainfall, absorb it, and infiltrate it into the underground. It can also act as a natural air conditioner and absorb large amounts of carbon dioxide while producing oxygen. Many cities in the world, including Delhi, have initiated the vertical gardening concept with the vision to make their city greener. It is high time that Dhaka should be reconstructed in such a way to allow for it to become a green city (The Institution of Engineers Bangladesh Dhaka Centre [Producer], 2020). Further, the government can authorize provisions about rooftops gardening in building codes like the Bangladesh National Building Code (Chowdhury et al., 2020).

2. Instead of informal settlement clearance or relocation or rehabilitation, scopes identification for informal settlement up-gradation via participatory budget is suggested following any or multiple options like self-help, *in-situ* public housing, assisted (i.e., equity-based affordable) community housing (Begum et al., 2018), co-managed informal settlement upgrading (Panday, 2020), etc.

3. Water-urbanism (i.e., a wet, hydrological and softer infrastructure approach) (Ahmed, 2017) practice is required than prevailing dry or harder approach by reinventing interconnected water networks, redevelopment of wetlands, reconstruction of land-water transports (Siddiqua, 2020). Dig–elevate–dwell principle (Islam, 2001) can be applied on low-lying lands to minimize the obstruction of floodwater flow. Specific to Dhaka's context, the recommended proposals and plans for future drainage

infrastructure improvements are advised to remain the same as stated in RAJUK's DAP, Narayanganj City Corporation's Concept Vision Plan, and DWASA's Sewerage Master Plan (Dasgupta et al., 2015).

4. Polluting industries should always be transferred downstream a river (Rampley et al., 2020), as the water contamination therein is controlled by upstream flow (Islam et al., 2015). As unreliable figures exist on effluent disposal to the environment after adequate treatment, the idea of used (waste) water injection to the city's groundwater should be avoided. Further, on-site sanitation systems, such as septic tanks and pit latrines should be encouraged before releasing them to the sewage system. In this context, citizen science (van Noordwijk et al., 2021) can be applied for the active participation of the stakeholders.

5. For the decrement of air pollution in the future, it is recommended to install catalytic converter in the vehicles and reduce sulphur in diesel through hydro-desulphurization (HDS) (Alam, 2010). It is necessary to immediately relocate smoke-emitted industries (Ahmed & Mahmood, 2011).

7.3 Research

It is suggested not to face a problem when it arrives; instead, it is more important to find what problems await in the future before it arrives through researching with enough knowledge. To be specific:

1. Reconceptualize water/delta by policymakers, engineers, urban planners, designers and architects, coevolution of nexus across city economy, ecology, and living condition.
2. Systematic study and development of more technical know-how applying citizen science. New (solution) models to introduce after gaining more knowledge for implementation.
3. Formulation of multi-objective planning tools which is multidisciplinary and multi-dimensional in nature, a digitalised decision support system for better coordination.
4. Feasibility/model studies to be done in advance applying variable future scenarios to get response characteristics of water resource systems.
5. Propose social models that can build up community ownership, promote sharing value, and encourage cleanliness culture, water reuse, recycling, gender-friendly behaviours, online payments, etc.

8. CONCLUSION

The delta urbanization process should keep urban transferability as the prime choice that provides the scope of transferring a city location to shifting the delta's waters. Understanding the water system must get priority before implementing any measures. But when these choices are overlooked with negligence at the advent of the urbanising process, then there is no turning back in the mid-way to establish this facility because it will result in irrecoverable loss due to the permanent interlinkage of different urban sectors. As a consequence, the urban area has to go through the adaptive phase in order to face the challenges like mushrooming of squatter settlements in and around the cities, the establishment of permanent constructions that are gradually replacing room for water, and also with emerging issues such as land degradation, unsafe water, and air pollution. This further leads contemporary urbanism to face pressures for basic facilities and the decent standard of living required for human dignity. Now half-hazard settlements are unlikely to go away, migration is unlikely to stop, and frontline battling with climate-change-induced challenges are inescapable for urbanising delta, i.e., Dhaka. On top of that, this megacity is starting at another crisis of tackling pandemic outbreaks and its extra challenge of handling disposals of single-use biomedical and plastic usage.

Thus, when there is no chance of urban transferability, the only choice left in hand is to follow the recommended guidelines stated above in Section 7. The most noteworthy among them are multi-objective planning that includes integrated land-use, regulate ecological zoning, and slum up-gradation; enabling environment by inter-sectoral and cross-sectoral collaboration or implementation by the same organisation, blending of top-down and bottom-up approaches, coordinated decentralisation, etc.; micro-level monitoring; and awareness build-up for recycling strategies. These recommended guidelines pave the way to cope with the complexity that can at best minimize risks, merely mitigate and transform risk to other parts of the deltas. In fact, most of the time these recommended guidelines can result in nothing but a failure because, so far, urbanization in bottom catchment promoted fortification against the hydro-ecological functions of nature with only just a dry approach comprising hard infrastructures and no concern about water and people in it at all. The recommended guidelines will only be efficient when people within the delta and the water urbanism are taken into account while forming plans and policies. Furthermore, for a delta, if long-term plans and policies can be ensured to avoid sudden rapid responses

to the challenges, then these guidelines will give much more promising and practical outcomes to sustain a stable Environmental Kuznets Curve (EKC). Specifically, identifying the current situation in quantifiable terms (e.g., numeric values, percentages, scores, indices), setting a quantitative target to measure progress, and tracking data for specific measurable and meaningful outcomes are practical and timely demands for any plan/policy to succeed. These long-term plans and policies must include digitised monitoring facilities and ensure citizen science with open data sources within organizations for transparency. In this context, with current conditions and guidelines for the future, Dhaka city is standing with a great many lessons for the deltaic urban areas around the world. However, no solution fits all, hence, integrated tailor-made strategies are needed to incorporate in the adaptive pathway settings.

9. DATA AVAILABILITY STATEMENT

All data, models, and code generated or used during the study appear in the submitted article.

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Annex-1: List of experts and webinars used for retrieving qualitative information

Experts	*Event/Webinar*
Head of the Wageningen Project Office, Dhaka, Bangladesh and active member of Delta Alliance	River Conservation Club [Producer]. (2020). Webinar: Online River dialogue on Challenges of River Management. [Video]. https://www.facebook.com/riverconservationclub/videos/1179293015752603
Country Director of Water Aid Bangladesh Professor, Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering and Technology (BUET) Professor, Geology, Dhaka University (DU) Professor, Architecture, BUET Managing Director, Dhaka WASA Managing Director, Building Technology & Ideas Ltd. Director, Urban Development Directorate Chief Town Planner, Chittagong Development Authority Director, Bangladesh Water Development Board	RAiN Forum [Producer]. (2020). Webinar: Rainwater Harvesting for Resilient City. [Video]. https://www.facebook.com/RAiNForum.org/videos/590800654905455/
Chairperson, BRAC (International NGO of Bangladesh), Executive Chairman, Power and Participation Research Centre (PPRC) ARISE Bangladesh Advisory Board Member	BRAC James P Grant School of Public Health [Producer]. (2020). Webinar: COVID-19 Impact on Urban Informal Settlements. [Video]. https://youtu.be/CxO8SUj-tsQ
Professor, IWFM, BUET and a Lead Author on the IPCC's Sixth Assessment Report	The Institution of Engineers Bangladesh Dhaka Centre [Producer]. (2020). Webinar: Technical Discussion Meeting on World Cities Day. [Video]. https://www.facebook.com/iebdc/videos/379235380056441
Professor Emeritus, BRAC University Former President and current Vice President, Real Estate and Housing Association of Bangladesh Managing Director, Building Technology and Ideas Ltd. Project Director and President, Bangladesh Architects Institute General Secretary, Bangladesh Institute of Planners Joint General Secretary and Consultant, Detailed Area Plan Professor, Urban and regional planning, BUET Former Chief Architect and current Vice President, Institute of Architects Bangladesh Chief Executive, Bangladesh environmental lawyer Association	Bangladesh Institute of Planners and Bangladesh Architects Institute [Producer]. (2020). Webinar: A virtual roundtable meeting on Future Dhaka and Detail Urban Area Plan. [Video]. https://www.facebook.com/groups/1802483560017928/posts/2721447471454861/
Joint Secretary, Bangladesh Environment Movement Chairperson BRAC Professor, Water Resources Engineering, BUET BAPA (urban activist) Researcher, Bangladesh Centre for Advanced Studies (BCAS) Professor, Urban and Regional Planning, Jahangirnagar University Professor, Political Science, DU Head of the Wageningen Project Office, Dhaka, Bangladesh	A national event on Hydro-social Deltas: Understanding flows of water and people, Dialoguing New Dhaka, organized by IHE-Delft Institute for Water Education, Delft, Netherlands, with Wageningen University and Research (WUR), Bangladesh Centre of Advanced Studies (BCAS) and Flood Hazard Research Centre (FHRC) on 19 November 2019

AUTHORS' DECLARATIONS AND ESSENTIAL ETHICAL COMPLIANCES

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2	Author 3	Author 4	Author 5	Author 6
Conceived and designed the research or analysis	Yes	Yes	Yes	No	No	Yes
Collected the data	Yes	Yes	Yes	Yes	Yes	No
Contributed to data analysis & interpretation	Yes	Yes	No	Yes	Yes	No
Wrote the article/paper	Yes	Yes	No	Yes	Yes	No
Critical revision of the article/paper	Yes	Yes	No	No	No	No
Editing of the article/paper	Yes	Yes	No	No	No	No
Supervision	No	Yes	No	No	No	No
Project Administration	No	No	No	No	No	Yes
Funding Acquisition	No	No	No	No	No	No
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Research involving human bodies (Helsinki Declaration)

Has this research used human subjects for experimentation? No

Research involving animals (ARRIVE Checklist)

Has this research involved animal subjects for experimentation? No

Research involving Plants

No plant was used to conduct this research.

Research on Indigenous Peoples and/or Traditional Knowledge

Has this research involved Indigenous Peoples as participants or respondents? No

(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)

Have authors complied with PRISMA standards? No

Competing Interests/Conflict of Interest

Authors have no competing financial, professional, or personal interests from other parties or in publishing this manuscript.

RIGHTS AND PERMISSIONS